ENVIRONMENT AND ECOLOGY AT THE BEGINNING OF 21ST CENTURY

Editors

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Life Cycle Assessment of Building Products in the Context of Ecological Architecture and Academic Research in Turkey

Z. Sevgen PERKER

1. INTRODUCTION

Currently, environmental problems have become highly complex. Any world country that feels responsible for fighting environmental problems operate with the objective of developing and implementing policies for fighting such problems. Any individual of the society needs to struggle with environmental problems that have a power to affect the life in every little aspect, putting a common effort. Therefore, a variety of professional disciplines keep the concept of "ecology" on their agenda and put effort in generating solutions to environmental problems based on their professional field. Within this scope, current architecture discipline has primarily focused on "ecological architecture". Ecological architecture involves minimizing the need of a building for energy; selecting a design and materials based on a particular purpose and even contributing to generation of energy required by the building by means of selection of materials and systems to be integrated into building, in other words, aiming at design, manufacturing, use and recycling in compliance with ecologic principles (Berber, 2012).

The need for buildings is increasingly growing in parallel with the increased world population. This increased need for buildings results in growth of building industry, and accordingly increase in manufacturing of building materials. Activities for housing mean, on one hand, further consumption of natural sources and energy, on the other hand, increased environmental pollution, thus "ecological building product", which is the major component of ecological architecture, become more and more important.

Ecological building product can be defined as a durable, long-lasting product that respects the nature; consumes less energy as much as possible when manufacturing, is harmless to both environment and human health during production, use and demolition of the building, requires low cost for maintenance and repair, and recyclable and needs a little energy for recycling (Tönük, 2001). Ecological architecture can be achieved by ecological building products.

2. BUILDING PRODUCTS – INTERACTION WITH ENVIRONMENT

Building products always interact with environment and human during the period from their manufacturing to their demolition when necessary. An adverse interaction will hamper sustainability of life. It is therefore very important to systematically assess interaction of building products with environment and human health, identify and resolve problem aspects.

Major environmental problems caused by building products include global warming, acidification, thinned ozone layer, air and water pollution, depletion of water and energy resources, loss of biological diversity, altered natural life, impaired human health, and impact of photochemical smog (Bayraktar, 2010).

Defined as increase in average temperature measured in land, sea and air, the global warming is primarily caused by greenhouse effect due to released gasses into atmosphere (Berber, 2012; URL-1). Release of greenhouse gasses occurs with consumption of fossil fuels, reduced forestland and changed practices in the use of soil. The major contribution to this comes from the built environment. 50% of global pollution of CO_2 results from the built environment for which the building industry is the main responsible (Khasreen, Banfill, & Menzies, 2009).

Acidification is defined as pollution of surface water and soil by acidic pollutants, and transmitted to ecosystems through acid rains (URL-1). The main cause of acidification is also fossil fuel. It is a known fact that fossil fuel is used to manufacture most of building materials (Bayraktar, 2010). Therefore, building materials that are manufactured using fossil fuels appear to cause global warming as well as acidification. On the other hand, acid rains accelerate wearing of many building materials, resulting in decreased service life of such materials.

It is known that materials that consume ozone are used in certain areas of building industry and such materials lead to thinning of ozone layer (Bayraktar, 2010). Beside, industrial production is known to cause air and water pollution and higher consumption of water resources and energy resources. This results in loss of biological diversity as well as alteration of natural life. Having an important role in current world industry, building material sector makes a substantial contribution to adverse environmental impacts we have mentioned.

On the other side, a number of solid, liquid and gaseous pollutants resulting from industrial production are a threat to human health. In addition, manufacturing process of various building materials has adverse effects on health of workers in the industry while various construction chemicals such as adhesives, dyes, and care products adversely influence the health of user (Bayraktar, 2010).

Photochemical smog is caused by photochemical reaction that occurs with effects of sunlight in air polluted by emissions generally from industrial processing (URL-2). The smog generated during manufacturing and transport of building materials is known to have adverse effects on both environment and human health.

3. LIFE CYCLE ASSESSMENT OF BUILDING PRODUCTS

Large quantities of raw materials are used for building industry and high amount of energy is consumed across the world. On the other hand, both manufacturing processes and composition characteristics of building products result in a variety of environmental problems and become a threat to human health. This has required an ecological assessment of building materials before they are involved in construction action. “Life Cycle Assessment” is adopted as a supporting approach to decisions based on ecological principles in selecting both technology and products for building action, and has been used by the building industry since 1990s (Bribián, Capilla, & Usón, 2011; Khasreen *et al.*, 2009; Zabalza, Aranda, Scarpellini, & Diaz, 2009). Currently, there are many academic studies that ecologically address to various building products through “Life Cycle Assessment” (Aksel Yıldız, 2014; Alkaya, Böğürcü, & Ulutaş, 2012; Banar & Cokaygil, 2011; Bayraktar, 2010; Bowyer, Bratkovich, Fernholz, & Lindburg, 2009; Çamur, 2010; Çelebi, Sezgin, & Gültekin, 2009; Eren & Başarır, 2013; Güler, 2011; Gültekin, 2006; Hozatlı, 2013; Karaman Öztaş, 2014; Kaya & Türkeri, 2010; Kumbhar, Kulkarni, Rao, & Rao, 2014; Nicoletti, Notarnicola, & Tassielli, 2002; Pajchrowski, Noskowiak, Lewandowska, & Strykowski, 2014; Traverso, Rizzo, & Finkbeiner, 2010; Üçer, 2012; Werner & Richter, 2007; Zabalza *et al.,* 2009).

Life cycle of building products can be defined as the whole of successive and interactive processes starting with procurement of raw materials and ending with use of product (Gültekin, 2006; Tuna Taygun & Balanlı, 2005). Life cycle of building products mainly involves six processes including procurement of raw materials, manufacturing of building product, using building product in the building, use, maintenance and repair of building product, dispose of building product, and recycling of building product. The transporting process that is performed among all processes is considered included in the life cycle (Figure 1, URL-3)

The process for procurement of raw materials involves deriving raw materials and energy resources and transporting raw materials to manufacturing location of building product. In this process, energy, labor and capital are used. The raw materials generate air pollution, liquid and solid fuel at the end of the process. The same process is likely to damage the nature. Excavation of land during mining activities and unplanned tree cutting may disturb the natural topography. For example, the land topography can be severely damaged where raw materials of building materials, e.g., iron, cement and aggregate, are extracted. Furthermore, dust and pollutants hazardous to environment and human health can be released during resource output and transporting to manufacturing plant. In the process for procurement of raw materials, while chose of local products provides benefit to the economy, it is required to minimize damages (e.g., energy consumption, wastes) that may occur during transporting raw materials; to pay attention to preserving natural topography as much as possible; and using wastes of building industry and other industries for manufacturing building products (Gültekin, 2006; Onat, 2004; Sev, 2009; Tuna Taygun & Balanlı, 2005; Yalçınkaya, 1995).

Manufacturing process of building product involves phases such as processing raw materials that are transported to use for making a finished building product; obtaining, packing and distributing the building product. Energy, labor and capital are consumed in this process as well, and raw materials and equipment are used. At the end of the process, building products generate by-products, air pollution, and liquid and solid fuels. For example, generation of wastes and use of energy are very high during melting stage in manufacturing process for metallic building products. On the other hand, a variety of pollutants can be released depending on properties of such metal. For example, the lead is one of the metals that require taking precautions due to its toxic composition and pollution from its manufacturing process. Similarly, volatile organic compounds (VOCs) are emitted into atmosphere and a very high energy is consumed during manufacturing of plastic building products (Gültekin, 2006; Tuna Taygun & Balanlı, 2005). As is known, a very large amount of energy consumed for manufacturing of building products results in global warming, acid rains and generation of photochemical smog. The manufacturing process is a life cycle process in which the highest amount of energy is consumed, thus producing the highest volume of chemical substances, particularly gaseous pollutants, and therefore having adverse effects on workers' health. In this process, the distance of manufacturing plant from the location where raw material is supplied causes increase in energy consumption. On the other hand, a very large volume of water is used for manufacturing many building materials, especially paper, cement and metals. The waste water that is generated at the end of the process and contains pollutants gets mixed with streams and seas, resulting in water pollution. In the manufacturing process for building product, it is required to locate manufacturing plants near areas of raw materials; to take measures for reducing air, soil and water pollution; to process materials as less as possible in order to minimize consumption of energy and water used for manufacturing; to reduce pollution in order to protect workers' health during manufacturing; to improve inner air quality; to select a packing material of building products in accordance with ecological principles; and to develop alternatives to building products that require a high amount of energy for manufacturing (Onat, 2004; Sev, 2009; Tuna Taygun & Balanlı, 2005; Yalçınkaya, 1995).

Energy, labor and capital are consumed and building products and equipment are used during application of building products to building. At the end of the process air pollution and solid wastes are generated. In-building air pollutants from certain building products pollute interior of building and damage the human health, especially during use of such building products. For example, specific adhesives used for application of building products such as ceramic, carpet and linoleum or volatile organic compounds (VOCs) released during application of paint and varnish are likely to cause damage to persons who apply such products. On the other hand, loss of materials may occur due to incorrect applications on the construction site during application process. This is unfavorable for efficient use of raw materials. Application should minimize the loss of materials during application of building products to building (Onat, 2004; Sev, 2009; Tuna Taygun & Balanlı, 2005; Yalçınkaya, 1995).

The longest process in the life cycle of building products is use, maintenance and repair process. This process including use, maintenance and repair of building product (e.g., cleaning, replacement of damaged and worn parts) consumes energy, and at the end of the process expired building products produce air pollution and liquid and solid wastes. Consumption of energy used by overall building, and environmental impact of the building, change depending on whether energy effectiveness of building product is low or high during mentioned process. On the other hand, materials that release toxic gases during use cause adverse effects on the inner air quality, thus become a threat to user's health. Chemical materials that are contained in composition of specific building materials or used for their manufacturing can cause releasing of polluting gasses into interior even after years. Perhaps the most significant example of this would be release of heat and toxic gasses by insulating tapes used for plastic-based joinery. It is important to choose materials that have high energy effectiveness and have favorable effects on interior air quality in order to reduce energy consumption by building in the process for use, maintenance and repair of building products (Gültekin, 2006; Onat, 2004; Sev, 2009; Tuna Taygun & Balanlı, 2005; Yalçınkaya, 1995).

The demolition process occurs when useful life of building product expires. In this process, energy, labor and capital are consumed, and equipment is used for demolition activities. At the end of this process, energy, air pollution, liquid and solid wastes are produced. Different wastes that are generated from demolition of building products depending on selected demolition technology can cause damage to environment and human health. In demolition process it is required to use of demolition methods to reduce air pollution; to perform demolition, disassembly or replacement using fast and easy methods as much as possible; to minimize energy consumption by equipment used; and to carefully select methods in consideration of workers' health (Gültekin, 2006; Onat, 2004; Sev, 2009; Tuna Taygun & Balanlı, 2005; Yalçınkaya, 1995).

During recycling process for building products, energy, labor and capital are consumed and equipment is used for recycling activities. Raw materials or products from recycling of building product can produce air pollution, liquid and solid wastes at the end of the process. The amount of energy required for recycling is often much lower than the amount of energy used for initial manufacturing. For example, the energy used for recycling of aluminum is 10-20% of initial manufacturing. Materials suitable for recycling include plastics, glass, metals, concrete, brick, steel, and wood. Despite this however, technology used for recycling may rarely need using more energy than initial manufacturing, thus pollutants may be produced by the recycling process itself. It is required to pay attention to using recyclable building products in order to reduce damages and energy used during disposal of building products; to avoid difficult, complex, high-cost recycling processes as wells as harmful processes to environment and human health; to choose appropriate methods for environmental impact and human health in disposal of wastes that cannot be recycled; and to enable solid wastes (e.g., dross) produced from generation and use of energy to be used for manufacturing of building products (Sev, 2009; Tuna Taygun & Balanlı, 2005; Yalçınkaya, 1995).

Use of land transportation to transport building materials causes increase in both environmental pollution and energy consumption. Motorways constructed especially for land transportation, on one hand, affect the natural land structure, on the other hand, causes noise pollution, and the fuel used for transport causes air pollution. It is important to use maritime transport and railway transport as much as possible to reduce pollution (Onat, 2004).

4. ACADEMIC RESEARCH IN TURKEY

A Life Cycle Assessment is an ecological assessment system that addresses to different categories from material scale to location scale across the world. It is important to understand and generalize this system, which provides support in making decisions on creating healthy built environment and building with reduced adverse effects on ecological system, especially in countries that have higher activities in building industry. Turkey is a country that substantially owes its development to building industry and has a significant share in the global market through its building products (INTES, 2014). In this respect, Turkish academic research on assessing life cycle of building products is very important. In this context, this section of the study addresses and reviews Turkish dissertations, research articles and conference proceedings that contain "life cycle" in their title and concern building materials in the field of architecture.

In the review, we found a total of 15 researches since 2005. Of these, 8 were dissertations, 5 were articles, and 2 were proceedings. In distribution of these researches by years, the number of relevant academic articles has been increased since 2010 in particular. All of the reviewed researches contain life cycle assessment system for building products and general information on assessment; however each study used a different building product as a sample. Building products included in Turkish studies on life cycle assessment of building products by years are as follows respectively: PVC Window Frame, Wallpaper, Reinforced Concrete Wall with Glass Fibers and Polypropylene Fibers, Cement, Thermal Insulation Materials, Outer Wall, Wood, Vinyl and Laminated Parquet, Masonry Wall, Insulation Materials, Steel Structures, Steel Building Components and Expanded Polystyrene Foam. Table 1 lists Turkish academic research life cycle assessment for building products (Table 1).

The research by Tuna Taygun performed in 2005 and 2011 and the research by Tuna Taygun and Balanlı performed in 2005 defined the Life Cycle Assessment and investigated in detail a variety of models used to assess life cycle of products, affecting product, period for affecting, affected environmental groups, and results from being affected in order to create a model. The same research by Tuna Taygun performed in 2005 sampled the created model on PVC window profile (Tuna Taygun, 2005, 2011; Tuna Taygun & Balanlı, 2005).

The study by Gültekin performed in 2006 reported that environmental impact of building products needed to be assessed throughout their life cycle in order to enable people to have a healthy life and improve the quality of environment, and the same study defined the life cycle which was described in detail including supply of raw materials, manufacturing, construction, use, demolition and after-demolition stage. In this study, an open-ended model was proposed to assess environmental impact of building products throughout their life cycle. This model was materialized by an example study in which environmental impacts due to maintenance and repair of wallpapers at use phase were assessed (Gültekin, 2006).

The research by Çelebi, Sezgin and Gültekin in 2009 investigated software programs used to assess life cycle of building products. In the same research, details of a software program were provided and that program was used to assess the life cycle of reinforced concrete wall with glass fiber and polypropylene fiber *(Çelebi et al., 2009*).

In the research by Bayraktar performed in 2010, an assessment system was developed to identify environmental impacts on life cycle of building materials, taking into account Turkey’s current state, and it was aimed to enable decision-makers, at design phase, to choose building materials that would cause the least harm to the environment. For this purpose, initially ISO 14040 – Life Cycle Assessment, a standard used to identify environmental impact of building, building materials and products, and the system based on this method and equipment were reviewed. In the light of review, a system was proposed to assess environmental impacts of building materials during their life cycle in accordance with national facilities and constraints imposed for environmental impacts, which was based on the Life Cycle Assessment and considered reviews on Turkey’s current situation for environmental issues.

Table 1. Turkish Academic Research on Life Cycle Assessment for Building Products

Authors	Title (Year)	Building Material and Component (General)	Building Material and Component (Specific)	Thesis	Journal Article	Conference Paper
Tuna Taygun, G.	A model for life cycle assessment of building materials (2005)	X	PVC Window Frame	X		
Tuna Taygun, G. Balanlı, A.	Building product in processes for life cycle – environmental interaction (2005)	X	---		X	
Gultekin, A.B.	Proposal of a model for assessment of the environmental impacts of construction products within the context of life cycle assessment methodology (2006)	X	Wallpaper	X		
Celebi, G. Sezgin, F. Gultekin, A.B.	Implementation example for life cycle assessment and GaBi software program (2009)	X	Reinforced Concrete Wall With Glass Fibres and Polypropylene Fibres			X
Bayraktar, F.T.	A proposal of building material life cycle assessment system for Turkey (2010)	X	Cement	X		
Çamur, C.	Environmental evaluation of thermal insulation materials by life cycle assesment methodology (2010)	X	Thermal Insulation Materials	X		
Kaya, U. Turkeri, N.	Life cycle assessment of building materials used for external wall systems (2010)	X	Outer Wall			X
Guler, S.B.	Analysis of the protection and repair methods of wood within the scope of its life cycle (2011)	X	Wood	X		

Table 1: Continued

TunaTaygun, G.	Life cycle assessment of building products (2011)	X	---		X	
Banar, M. Çokaygil, Z.	Life cycle comparison of floor covering materials: vinyl covering and laminated parquet covering (2011)	X	Vinyl and Laminated Parquet		X	
Ucer, D.	Life cycle assessment of masonry wall types using simulation technique (2012)	X	Masonry Wall	X		
Alkaya, E. Bogurcu, M. Ulutaş, F.	Lıfe cycle analysis and implementations for insulation materials (2012)	X	Insulation Materials		X	
Eren, O. Basarir, B.	Life cycle assesment of steel structures within the framework of sustainability (2012)	X	Steel Structures		X	
Aksel Yildiz, H.	Evaluation of reuse and recycling possibilities for steel building components in the life cycle (2014)	X	Steel Building Components	X		
Karaman Oztas, S.	A model proposal for life cycle impact assessment for the Turkish building materials sector (2014)	X	Expanded Polystyrene Foam	X		

The proposed system was sampled on cement, a building material (Bayraktar, 2010).

The objective of the study conducted by Çamur in 2010 involved Life Cycle Assessment of expanded polystyrene (EPS), a thermal insulation material that plays an important role in preserving energy and is widely used for buildings, and rock-wool that can be used as an alternative to EPS as well as identifying their environmental impact based on comparison. In the same study, GaBi 4 software was used to assess environmental impacts of these thermal insulation materials (Çamur, 2010).

The research by Kaya and Türkeri conducted in 2010 underlined that external wall systems should be designed by components that have the least adverse effects on the environment under influence of external factors. The aim of this research was to present environmental performance of wall core, waterproofing and coating materials, which are system components manufactured in Marmara Region in Turkey, through Life Cycle Assessment. In the same research, a survey was conducted with relevant companies and results were interpreted (Kaya & Türkeri, 2010).

In the research performed by Güler in 2011, an important stage of life cycle of wood, an organic material, that is, use – maintenance – repair stage was discussed and examined. This research described factors causing degradation of wood, various elements affecting wood used in buildings and chemical, structural protection and repair methods to protect wood materials (Güler, 2011).

The research conducted by Banar and Çokaygil in 2011 was aimed to investigate the vinyl and laminated parquet flooring that are widely chosen due to their low cost and ease of use through Life Cycle Assessment. In the same research, these materials were assessed by a software program in four impact category: depletion of abiotic resources, global warming, toxicity on human, and acidification (Banar & Cokaygil, 2011).

The research performed by Üçer in 2012 provided information first on Life Cycle Assessment and types of masonry walls. In the research, the end-life stages of masonry walls were defined as landfill, reuse, and recycling. Identified types of masonry walls were investigated by a software program in regard to defined stages (Üçer, 2012).

The research conducted by Alkaya, Böğürcü and Ulutaş in 2012 included a variety of thermal insulation materials such as glass wool, rock wool, expanded polystyrene foam (EPS), extruded polystyrene foam (XPS) and polyurethane foam (PUR) that are largely used in the world and in Turkey. These materials were evaluated for wastes and emissions to environment at different stages including procurement of raw materials, manufacturing, use, transportation and waste disposal during their life cycle (Alkaya *et al.*, 2012).

The research performed by Eren and Başarır in 2013 evaluated life cycle of steel structures by identifying various criteria such as sustainability, resource efficiency, energy efficiency, and recycling (Eren & Başarır, 2013).

The research by Aksel Yıldız in 2014 reported that the building industry accounted for 44% of overall consumption of materials in the world, and also underlined that emission of greenhouse gasses generated by use of buildings was responsible for around 40% of overall amount of emission worldwide. In the same research, it was predicted that environmental impacts of buildings are likely to increase by 60% in 2030 with increased world population. In this sense, the research placed an emphasis on reduction of environmental impact of buildings in their life cycle. This research reported that currently, steel is widely used in many buildings from high-rise housings to skyscrapers, bridges to commercial buildings for its strength, durability, versatility, low-cost, flexibility, aesthetics, lightweight and ease of application; and that it was important to address steel structures in terms of environment during their life cycle with increase in their use. The same research described the manufacturing methods and properties of structural steel with increased use, identified end-life interventions (waste management) in its life cycle, evaluated possibilities of reusing and recycling among possibilities of recovering, and an environmental comparison was made based on data in the literature. In addition, an environmental comparison was conducted using a software program between direct manufacturing of structural steel from raw material and manufacturing through recycling (Aksel Yıldız, 2014).

The research performed by Karaman Öztaş in 2014 was aimed to develop a model for Life Cycle Assessment addressing entire life cycle of building materials manufactured in Turkey, and a midpoint approach model was recommended based on ISO 14040 standard. Environmental issues of Turkey include 11 environmental effect categories caused by building materials, considering effect categories that are mostly used in EN 15804 standard and current models for Life Cycle Assessment. For seven effect categories among selected ones, identification models and category indicators were selected based on EN 15804 standard. For the remaining 4 effect categories, identification models and category indicators were determined based on Turkey-specific data. A weighting coefficient was determined for these effect categories and Turkey was divided into different risk zones by means of 11 selected environmental impact categories in regard to environmental issues based on weighing results. This model was tested on the expanded polystyrene foam material (EPS) (Karaman Öztaş, 2014).

5. CONCLUSIONS AND RECOMMENDATIONS

Building products have effects harmful to environment in any stages of their life cycle. Assessment of such adverse effects allows reducing harm of materials to environment and choosing environmentally friendly products. Life Cycle Assessment is an important method that is widely used to assess environmental impacts of building products, buildings, and any living environment with buildings during their life cycle. Local factors affect assessing environmental impacts and determining significance level of such impacts. Therefore, many countries create their own model for Life Cycle Assessment to assess their environmental status. The relevant academic research forms the critical base for establishing such models.

Academic studies addressed by this review involving Turkey appear to successfully examine life cycle of different building products; however there is a large number of building products and processes that have not yet been studied. In this respect, the number of relevant academic research needs to be increased. On the other hand, we identified that reviewed academic research had several problems with collecting data in particular. Therefore, it is important that Turkish manufacturers of building materials should quickly create an extensive database including data on input, output and manufacturing technology for products they manufacture. It is a joint responsibility of all nations to provide a healthy and sustainable living space to people in the world. In this sense, countries such as Turkey that has increased activity in building industry and possesses a high market share in building products should develop a “Life Cycle Assessment System for Building Materials” that is in compliance with their own national and environmental conditions and functions in harmony with international standards; and such created systems should be based on legal and scientific platform. The reviewed researches in this study are very comprehensive academic studies that can play a very important role in creating such system in Turkey. However, it is important to perform more similar studies.

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